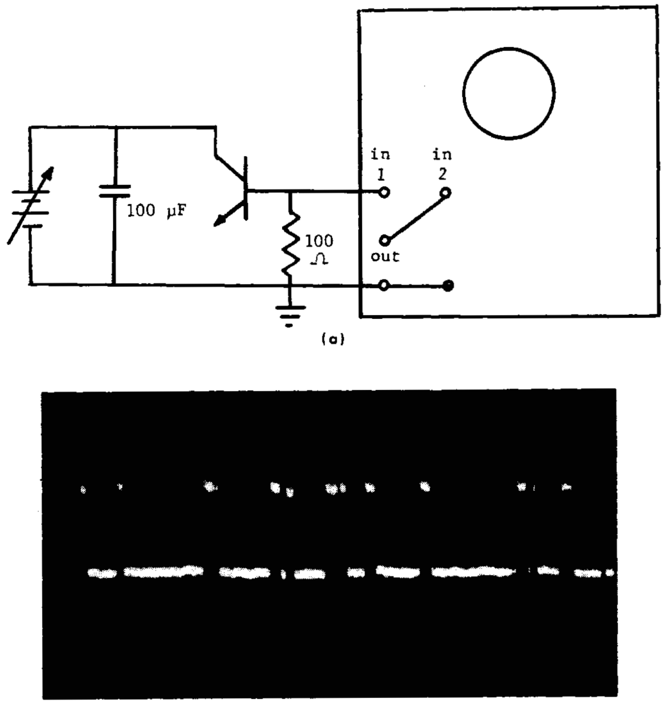

Fig. 4. (a) Test configuration, based on the method of Ricks and Pope [6], used to investigate the negative resistance regions of the collector-base volt ampere characteristic. (b) Voltage across the 100-ohm resistor as the load line was moved through the negative resistance regions of the characteristics. Horizontal scale: 50 μA/cm. Vertical scale: 0.1 ms/cm.

"Popcorn noise" and corresponding negative resistance regions in the V–I curve have also been observed in commercially available μA709 operational amplifiers. The μA709 operational amplifiers (from two semiconductor houses) which exhibited "popcorn noise" were opened and the metalization on the two input transistors selectively etched away. The reverse-biased base-collector characteristic on one of the devices in each amplifier exhibited a negative resistance region in the neighborhood of the bias current in the circuit application. In each one of the several hundred cases investigated, an unwanted negative resistance region has been found to exist at a point on the V–I curve corresponding to the junction bias current in the particular circuit application.

Since microplasmas are, in general, light emitting [4], we have attempted to view the emitted light. Again, in all devices exhibiting the phenomenon of "popcorn noise" we have observed localized light emission when the collector-base junction is reverse-biased to a point of negative resistance on the voltampere characteristic. We are presently completing our studies of the causes of the microplasma-producing defects, and will report on these in the near future.

We have correlated the existence of light emitting microplasma regions and corresponding negative resistance regions in the reverse-biased volt-ampere characteristic of the collector-base junction. It is concluded that "popcorn noise" and "microplasma noise" are equivalent.

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References

[1] W. E. Shockley, "Problems relating to p-n junctions in silicon," *Solid-State Electronics*, vol. 2, pp. 35–67, 1961.
[2] R. H. Haitz, A. Goetzberger, R. M. Scarlett, and W. E. Shockley, "Avalanche effect in silicon p-n junctions. I—Localized photomultiplication studies on microplasmas," *J. Appl. Phys.*, vol. 34, no. 6, pp. 1481–1590, 1963.
[3] K. Maeda and K. Suzuki, "Microplasmas in silicon p-n junctions," *Japan J. Appl. Phys.*, vol. 1, no. 4, pp. 193–201, 1962.
[4] A. G. Chynoweth and K. G. McKay, "Photon emission from avalanche breakdown in silicon," *Phys. Rev.*, vol. 102, no. 2, pp. 369–376, 1956.
[5] B. Senetzky and J. L. Moll, "Breakdown in silicon," *Phys. Rev.*, vol. 110, p. 612, 1958.
[6] R. S. Ricks and M. D. Pope, "Observation of microplasmas in GaP," *Japan J. Appl. Phys.*, vol. 2, pp. 520–521, 1963.

Coefficients for Feed-Forward MTI Radar Filters

Abstract—A solution is developed for determining the weighting coefficients of a feed-forward MTI Radar Filter so that maximum clutter attenuation is achieved. For certain realistic assumptions, the weighting coefficients which give maximum clutter attenuation are shown to be the same as those provided by cascading delay canceller filters.

Introduction

The application of feed-forward MTI filters for clutter attentuation is a well-known technique[1,2] for enhancing radar system performance when it is required to detect moving targets located in a stationary clutter background. Fig. 1 illustrates a feed-forward filter with arbitrary weighting coefficients. In this letter, a solution is presented for determining the value of the filter weighting coefficients so that maximum clutter attenuation is achieved.

Theory

The transfer function of the filter in Fig. 1 is given by

$$h(t) = \sum_{k=0}^{N} a_k \delta(t - k\tau) \tag{1}$$

where the a_k's are the weighting coefficients (assumed real), $\delta(\cdot)$ is the unit impulse function, and N is the number of equally spaced taps on the delay line. The magnitude squared of the Fourier transform of (1) is the so-called power transfer function of the filter and it can be written as

$$g(\omega) = \left(\sum_{k=0}^{N} a_k\right)^2 - 2\sum_{l=1}^{N}\left[\sum_{k=0}^{N-l} a_k a_{k+l}(1 - \cos l\omega\tau)\right]. \tag{2}$$

Clutter attenuation is defined as the ratio of the input clutter power to the output clutter power and it can be computed from the following equation:[1]

$$CA = \frac{\int_0^\infty C(\omega)d\omega}{\int_0^\infty C(\omega)g(\omega)d\omega} \tag{3}$$

where $C(\omega)$ is clutter-power spectrum as a function of frequency. The power spectrum of clutter signal is approximately equal to[3]

$$C(\omega) = C_0 e^{-[a(f/f_0)^2]} = C_0 e^{-f^2/2\sigma^2} \tag{4}$$

where C_0 is a constant, a is a parameter which depends on the type of clutter,[1,3] and f_0 is the radar carrier frequency. Substituting (2) and (4) into (3) and carrying out the integration yields

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[1] M. I. Skolnik, *Introduction to Radar Systems*. New York: McGraw-Hill, 1962.
[2] B. D. Steinberg, "MTI radar filters" in *Modern Radar*, R. S. Berkowitz, Ed. New York: Wiley, 1965.
[3] E. J. Barlow, "Doppler radar," *Proc. IRE*, vol. 37, pp. 340–355, April 1949.

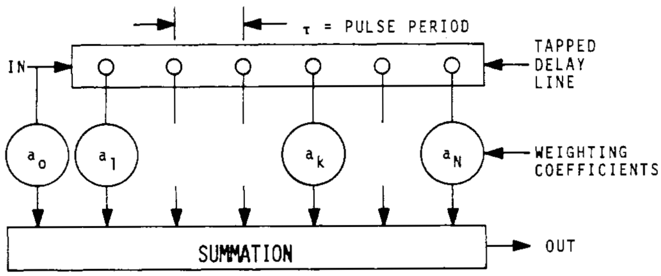

Fig. 1. Feed-forward MTI filter using a tapped delay line.

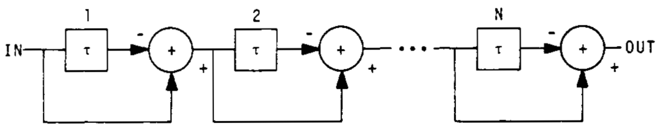

Fig. 2. N cascaded delay cancellers.

$$CA = \frac{1}{\sum_{k=0}^{N} a_k^2 + 2 \sum_{l=1}^{N} \left\{ \sum_{k=0}^{N-l} a_k a_{k+l} e^{-(Zl)^2/2} \right\}} \tag{5}$$

where

$$Z = 2\pi\sigma\tau = \frac{2\pi\sigma}{f_r}.$$

The criterion for maximizing the clutter attenuation ratio, which will be adopted in this letter, is to make the denominator of (5) as close to zero as possible. Using this criterion, for example, leads to the following equation for maximizing the clutter attenuation when $N=3$:

$$\begin{aligned} &a_0^2 + a_1^2 + a_2^2 + a_3^2 + 2(a_0a_1 + a_1a_2 + a_2a_3)e^{-Z^2/2} \\ &+ 2(a_0a_2 + a_1a_3)e^{-2Z^2} + 2a_0a_3e^{-9Z^2/2} = 0. \end{aligned} \tag{6}$$

A general solution to (6) (when a_i's are real) does not exist. However, when $0<Z\ll 1$, a situation which occurs in many practical systems, (6) may be approximated by

$$\begin{aligned} K &+ 2(A_1)\left(1 - \frac{Z^2}{2} + \left(\frac{Z^2}{2}\right)^2\frac{1}{2!} - \left(\frac{Z^2}{2}\right)^3\frac{1}{3!} + \cdots\right) \\ &+ 2(A_2)\left(1 - 2Z^2 + (2Z^2)^2\frac{1}{2!} - (2Z^2)^3\frac{1}{3!} + \cdots\right) \\ &+ 2(A_3)\left(1 - \frac{9}{2}Z^2 + \left(\frac{9}{2}Z^2\right)^2\frac{1}{2!} - \left(\frac{9}{2}Z^2\right)^3\frac{1}{3!} + \cdots\right) \approx 0 \end{aligned} \tag{7}$$

where K, A_1, A_2, and A_3 are constants defined in (6) and are a function of the filter weighting coefficients. If A_1, A_2, and A_3 are chosen so that the constant term and the coefficients of the Z^2 and Z^4 terms vanish, then the clutter attenuation will be maximum for the three tapped delay line case. Equation (8) shows the result of this choice.

$$\begin{aligned} A_1 + A_2 + A_3 &= -\frac{1}{2}K \\ A_1 + 4A_2 + 9A_3 &= 0 \\ A_1 + 16A_2 + 81A_3 &= 0 \end{aligned} \tag{8}$$

or

$$A_1 = \frac{-3K}{4}; \qquad A_2 = \frac{3K}{10}; \qquad A_3 = \frac{-K}{20}.$$

The above results lead to the following solution for the filter coefficients: $a_0=1$; $a_1=-3$; $a_2=+3$; $a_3=-1$.

In general, when $0<Z\ll 1$, the filter coefficients must satisfy the following equation in order to maximize the clutter attenuation formula in accordance with the adopted criterion:

$$\begin{bmatrix} 1 & 1 & 1 & \cdots 1 \\ 1 & 2^2 & 3^2 & \cdots N^2 \\ 1 & 2^4 & 3^4 & \cdots N^4 \\ \cdots & \cdots & \cdots & \cdots \\ 1 & 2^{2N-2} & 3^{2N-2} & \cdots N^{2N-2} \end{bmatrix} \begin{bmatrix} \sum_{k=0}^{N-1} a_k a_{k+1} \\ \sum_{k=0}^{N-2} a_k a_{k+2} \\ \cdots \\ a_0 a_N \end{bmatrix} = \begin{bmatrix} -\frac{1}{2}\sum_{k=0}^{N} a_k^2 \\ 0 \\ \cdots \\ 0 \end{bmatrix} \tag{9}$$

The solution to (9) is

$$a_k = \binom{N}{k}(-1)^k \qquad N \geq k \geq 0. \tag{10}$$

Conclusion

Equation (10) is the solution for the weighting coefficients (alternating binomial) which maximize the clutter attenuation for the multitapped delay line shown in Fig. 1. It is valid when Z is small, the coefficients are real (nonzero), and the clutter power spectrum is given by (4). It is interesting to observe that this solution, when substituted into (1), also defines the transfer function for N cascaded delay cancellers as shown in Fig. 2. This observation leads to the additional conclusion that the configuration shown in Fig. 2 will also maximize the clutter attenuation when the previously stated conditions for validity are met. Therefore, the maximum performance of these alternative configurations are theoretically equivalent.

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Maximum RF Power Transistor Collector Voltage

Abstract—The RF operating voltage of power transistors designed for operation in the HF, VHF, and UHF regions has been found to be greater than previously realized. This higher operating voltage is attributed to the slow response of the device surface with respect to the operating frequency of the circuit. Since most devices have breakdown voltages which are initially surface limited, their voltage operation at the higher frequencies is superior to the 60-cycle curve tracer behavior.

Introduction

RF power transistors, as well as other types, are prone to failure under conditions unique to their mode of operation. One of these modes relates to the generation of RF voltage levels which cause failure. The level of voltage at which transistor failure can occur is not always evident from techniques currently employed in measuring the appropriate transistor characteristics. Indeed, it is somewhat mystifying to encounter transistor RF collector voltage which exceeds voltages predicted from measurement for a given device. It is the purpose of this letter to more accurately define the level of maximum RF voltage which an RF power transistor can sustain prior to failure. In addition, a usually nondestructive technique will be described to ascertain this level of voltage.

Definition of Problem

In many, if not most, RF transistor power amplifier stages, the dc termination between emitter and base is either a low value of resistance, in

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